ADVANCING SCIENCE

Earth system science brings together data and understanding about the atmosphere, oceans, land and sea ice, ecosystems, land surface, and social systems to form a picture of our planet as a whole, including its changing climate. USGCRP uses Earth system observations, modeling, process understanding, and insights from the social sciences to advance scientific knowledge of the human and natural components of the Earth system, project possible future conditions, and provide the foundation for scientific assessment and decision support capabilities.

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ADVANCING SCIENCE
EARTH SYSTEM OBSERVATIONS

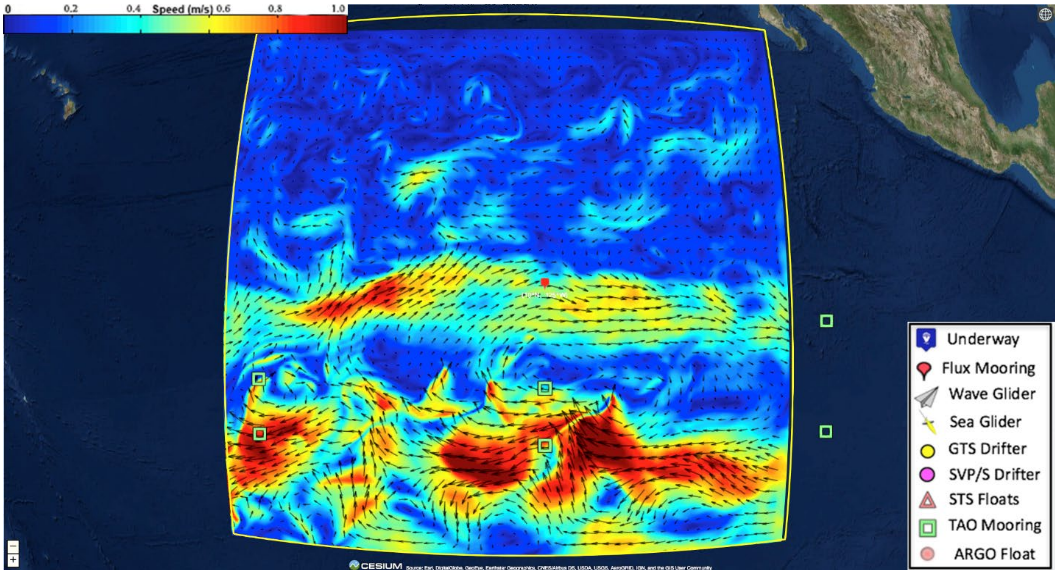
USGCRP agencies develop and maintain Earth observations systems that monitor the state of the planet over time and provide critical information used for planning related to agriculture, water resources, wildfire, air quality, severe weather, and other areas. Short-term observing campaigns are also used to target specific new areas of understanding and can complement longer term efforts or measurements made by different platforms. Satellite, aerial, *in-situ*, and field-based methods inform understanding of processes of change, both natural and human-caused, and support development and evaluation of Earth system models that provide insight into future changes. Observations efforts highlighted in this report span from pole to pole and capture processes of change across a range of timescales. In addition, a selection of USGCRP observational systems and campaigns scheduled for launch or completion during FY2017–2019 can be found at https://www.globalchange.gov/about/iwgs/obsiwg/compendium.

HIGHLIGHT 1
Strengthening critical observations of the tropical ocean and atmosphere

Upgrades to an observing network in the equatorial Pacific Ocean support valuable forecasts of global shifts in climate and extreme weather.

The El Niño Southern Oscillation (ENSO) is a natural climate phenomenon driven in part by the variability of ocean surface temperatures, atmospheric pressure, and trade winds in the tropical Pacific Ocean. ENSO events, occurring every two to seven years on average, cause widespread shifts in precipitation patterns and weather and climate extremes that impact agriculture, marine ecosystems, human health, disaster preparedness, and other sectors across the world. Using observations of ocean temperature and surface winds in the tropical Pacific, scientists are able to predict the ENSO cycle up to 12 months in advance and can provide forewarning of potentially damaging weather and climate conditions in many parts of the world. Real-time monitoring of ocean and atmospheric conditions through the **Tropical Pacific Observing System (TPOS)** supports this capability, but recent deterioration of a moored buoy network has put ENSO predictions and associated services at risk. The **TPOS 2020 Project**, running from 2014 to 2020, will oversee the transition to a more resilient observing system to meet research and forecasting needs of today and the future, including ocean temperature measurements that contribute to ENSO predictions. The First Report of TPOS 2020 proposed a network redesign that incorporates advances in observing technologies, process understanding, and modeling to improve the capability to monitor and predict ENSO and its impacts[2].

The U.S. contribution to TPOS 2020 is supported by NOAA and NASA, with scientific input from the U.S. Climate Variability and Predictability Program. NOAA recently made a significant investment to advance observing technologies in the tropical Pacific region to enhance ENSO research and predictions[3]. In addition, new technologies are being tested in conjunction with NASA's Salinity Processes in the Upper Ocean Regional Study 2 (SPURS-2) in the eastern tropical Pacific to improve understanding of interactions between the ocean and the atmosphere in these rain-dominated ocean regions, key to improving ENSO predictions (see figure)[4].



Forecasts of ocean surface current velocity in the Pacific Ocean off of Baja California generated in part using in-situ observations from NOAA's Tropical Atmosphere Ocean (TAO) moored buoy array (green squares), which is part of the Tropical Pacific Observing System (TPOS), and from measurements collected during the SPURS-2 satellite deployment over the tropical Pacific Ocean (red square). Depicted is a strong westward-flowing South Equatorial Current driven by the trade winds that blow from east to west across the equatorial Pacific. Changes to the easterly trade winds influence the progression of ENSO events. Forecasting these changes is integral to improving predictive capabilities. Source: NASA/Jet Propulsion Laboratory.

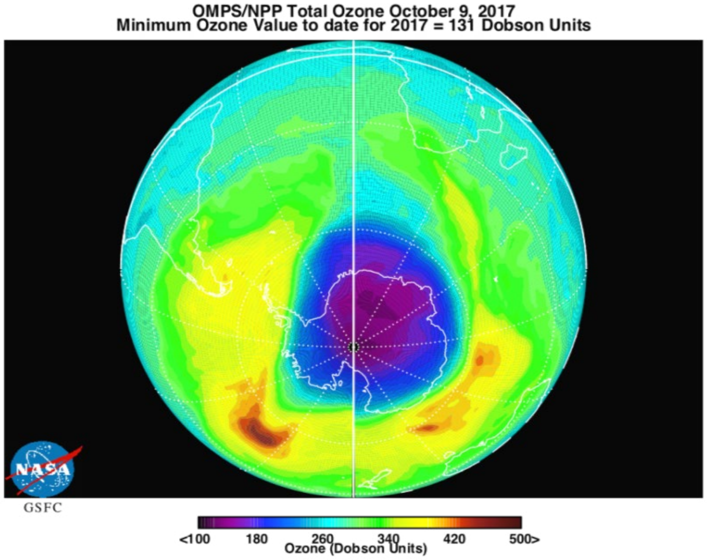
EARTH SYSTEM OBSERVATIONS

HIGHLIGHT 2
Monitoring recovery of the ozone layer

Interagency collaboration sustains long-term measurements that track the health of the ozone layer.

Ozone gas in the upper atmosphere protects the planet's surface from harmful solar radiation. The Antarctic ozone hole was discovered in 1985, increasing concerns about human emissions of gases that destroy ozone and the negative consequences for life on Earth. Two years later, the international community signed the Montreal Protocol, an international treaty designed to protect the ozone layer through regulation of ozone-depleting compounds. Later amendments completely phased out production of widely-used chemicals known as chlorofluorocarbons that destroy ozone. As a result of these controls, the ozone layer is expected to recover over the next few decades. The minimum ozone concentration in the Antarctic ozone hole—a good indicator of the overall health of the ozone layer—is higher than it has been since the 1980s, which may be a sign of ozone recovery (see figure).

Since 1990, NASA and NOAA have worked together to monitor global ozone using a series of NASA and NOAA Solar Backscatter Ultraviolet Radiometer (SBUV and SBUV/2) instruments. This program of almost 30 years of sustained effort demonstrates robust cooperation between these two agencies.



The 2017 annual minimum ozone detection of 131 Dobson Units over Antarctica was observed on October 9, 2017, about a week later than usual, indicating that ozone levels may be starting to recover. Source: NASA.

ADVANCING SCIENCE
CARBON CYCLE SCIENCE

Carbon cycle science integrates observations, modeling, and process studies to advance understanding of the flow of carbon through the Earth system. The addition of carbon-based greenhouse gases (such as carbon dioxide and methane) to the atmosphere, primarily through the burning of fossil fuels, deforestation, and land use change, is driving an increase in global average temperature and other linked changes[5]. These changes are altering the flow of carbon through different parts of the Earth system, affecting ocean and atmospheric chemistry, ecosystems on land and in the ocean, and the ability of these systems to remove and store carbon from the atmosphere[6]. Understanding the dynamics of these flows and their implications for future climate change is an ongoing challenge for carbon cycle researchers. Interagency field and modeling efforts are seeking to better understand how carbon-rich ecosystems such as tropical forests, coastal wetlands, and permafrost soils will respond to a warming climate over the 21st century and improve our ability to predict future climate change.

HIGHLIGHT 3
Predicting the future of tropical forests

Field research provides new data advancing our ability to project how tropical forests will respond to a changing climate.

Tropical forests store vast amounts of carbon and play a key role in regulating Earth's climate. As climate changes, these ecosystems have the potential to become a net contributor to global warming if they shift to releasing more carbon to the atmosphere than they absorb[7]. However, how these forests will be affected by a warming climate and changing atmosphere is still uncertain—and is critical for improving model projections of future climate change[8]. In the first experiment of its kind, researchers are testing how an intact tropical forest ecosystem responds to levels of warming expected over this century, including potential feedbacks to global climate. The **Tropical Responses to Altered Climate Experiment (TRACE)** is a multi-university project funded by a collaboration among the USDA-Forest Service, U.S. Geological Survey, and DOE. TRACE, initiated in September 2016 in El Yunque National Forest, Puerto Rico, is using heaters to warm plants and soils 7°F above surrounding temperatures—consistent with the projected range for the region by 2100. This temperature increase is also used in several higher-latitude warming experiments, enabling improved cross-site comparison of results. Initial measurements demonstrate the experiment's ability to consistently warm soil at depth to targeted temperatures.

While the 2017 hurricane season dramatically impacted the TRACE site, the project is continuing and will have a unique opportunity to explore how the ecosystem responds to a major natural disturbance. Over the next phase, researchers will measure temperature effects on a wide range of biological processes important to carbon cycling. Results will help reduce the uncertainties surrounding tropical forest responses to increasing temperatures, including whether these ecosystems will become net sources of carbon to the atmosphere rather than carbon sinks.

A warmed TRACE plot in the USDA-Forest Service Luquillo Experimental Forest in Puerto Rico. Three 15-foot diameter areas are warmed 7°F above surrounding temperatures with an array of six infrared heaters; three areas of the same size receive the same infrastructure but are not warmed. Source: Tana E. Wood, USDA.

HIGHLIGHT 4
Understanding carbon flows in vulnerable coastal wetlands

A new research network aims to accelerate discoveries in the science of these important natural carbon sources and sinks.

Coastal wetlands provide protection from wind and waves, support habitats and fisheries, and store large amounts of atmospheric carbon dioxide for centuries to millennia. These ecosystems can also be sources of greenhouse gas emissions to the atmosphere; wetlands that do not have the capacity to keep pace with sea-level rise, for example, can erode and release soil carbon rapidly to the atmosphere. Freshwater and brackish wetlands also emit methane, a more potent greenhouse gas over its atmospheric lifetime than carbon dioxide. High uncertainty surrounding the spatial extent and vulnerability of coastal wetland carbon stocks, as well as the dynamics of carbon storage and release, limits our ability to project future behavior of these ecosystems.

The NSF-funded **Coastal Carbon Research Coordination Network (CCRCN)** was established in 2017 with the goal of building a global community of scientists, policy makers, and non-governmental organizations working to reduce uncertainties and accelerates advances in carbon cycle science in tidal wetlands. CCRCN engages multiple agencies associated with USGCRP's Carbon Cycle Interagency Working Group. A steering committee comprising Federal and non-Federal organizations—including the Smithsonian Environmental Research Center, U.S. Geological Survey, Woods Hole Marine Biological Lab, and Conservation International—supervises and directs CCRCN priorities. Current activities, guided by community input, include the development and release of two online resources related to carbon in coastal wetlands: a literature review and open workflow supporting the EPA National Greenhouse Gas Inventory, released in December 2017, and a database of 1,500 publicly-available tidal soil carbon depth profiles from the contiguous United States, released in June 2018 as a companion to a journal article[9].

Mangrove forests store large amounts of carbon, protect the coastline from erosion, and provide shelter for many species. The image shows Landsat-based mapping of change in mangrove forests in the Florida Everglades, 2000–2016. Orange indicates areas of loss and degradation in mangroves; blue indicates areas of mangrove gains and regrowth. A) highlights areas of mangrove recovery; B) highlights areas of coastal erosion and mangrove loss; and C) highlights areas of inland mangrove degradation, with areas of inland degradation and resulting collapse of carbon-rich peat soils from saltwater intrusion shown in the inset. Source: NASA/Goddard Space Flight Center.

ADVANCING SCIENCE

EARTH SYSTEM MODELING

Earth system models simulate the state of the Earth system by incorporating the behavior of its many interacting components, both human and natural. These include the land surface, oceans, land and sea ice, atmospheric composition, clouds, and external influences on Earth's climate such as the sun's output and volcanic aerosols, as well as human influences such as greenhouse gas emissions. Models estimate the total influence of human and natural factors on the Earth system, and how the global climate might evolve over time depending on a range of future conditions. Earth system models rely on high-quality observations and detailed understanding of Earth system dynamics. Coordinated experiments across leading Earth system models are driving improvements in model ability to project future change and its associated impacts. Other research frontiers include modeling future climate conditions at higher resolution (i.e., at the regional scale) to support decisions and using economic impact models to assess how climate information can help managers in sectors such as agriculture plan for the future.

HIGHLIGHT 5

Modeling the impacts of climate variability and change on agriculture

Researchers are improving understanding of how shifts in climate conditions affect agricultural production, as well as the value of providing advance climate information to producers.

Climate variability and change affect agricultural yields and livelihoods[10]. Improving our understanding of how the interaction of climate variability and change affects agricultural production, particularly on regional scales that are more relevant to decision making, is an important research frontier. As part of the joint NSF-USDA National Institute for Food and Agriculture program on **Decadal and Regional Climate Variability Using Earth System Models**, researchers modeled the impacts of climate variability on water resources and agriculture in the Missouri River Basin. Simulated climate data and observed yields from a large variety of crops were provided as inputs to an economic impacts model along with various other choices that producers might make about their operations, including purchasing crop insurance. Using modeled decadal and regional climate predictions to optimize management decisions, researchers found that successful climate predictions for up to a year in advance could provide producers for that region alone with as much as $30 million in economic value, and for longer periods of up to five years, as much as $80 million[11]. Successful predictions, based largely on phases of the Pacific Decadal Oscillation—a long-lived pattern of climate variability that influences temperature and precipitation in the United States—could also inform adaptation decisions for producers.

HIGHLIGHT 6

Enhancing coordination among U.S. modeling centers

Collaboration across the modeling community supports critical experiments and scientific advancement.

U.S. climate modeling centers play a central role in understanding and predicting global change on seasonal to centennial timescales. They are engaged in the Coupled Model Intercomparison Project (CMIP), which produces climate projections underpinning the assessments conducted by the Intergovernmental Panel on Climate Change and the U.S. National Climate Assessment. Models developed by these centers are designed for different purposes, from providing operational forecast information to anticipating longer-term changes and improving scientific understanding of how different elements of the Earth system interact and change. The **U.S. Climate Modeling Summit (USCMS)**, convened annually since 2015, provides a venue for communication, collaboration, and coordination of these modeling activities. The Fourth USCMS, held in April 2018, featured discussions of the newest generation of climate models (CMIP6). An outcome of the meeting was a plan for comparison of model skill in simulating climate variability and an investigation of differences across models. During the summit, a workshop on "Land-Atmosphere Interactions and Extremes," involving discussion of modeling approaches and priorities across centers, allowed researchers to learn from one another's experiences in this rapidly evolving area of research and model development. The USCMS is convened by the USGCRP Interagency Group for Integrative Modeling, comprising agencies that sponsor U.S. climate modeling activities (including DOE, NOAA, NASA, and NSF) and those that are interested in model output application such as the USDA.

ADVANCING SCIENCE
SOCIAL SCIENCE PERSPECTIVES

Humans both drive and respond to change in the Earth system and can act to reduce risks arising from natural and human-caused changes and their interaction. The social and behavioral sciences are a key component of understanding the impacts of global change on human welfare, vulnerabilities in critical systems, and decision making in response to change. Improving integration of social science insights on climate change impacts, vulnerabilities, and the social processes of responses into USGCRP research and activities is an ongoing goal for the Program.

HIGHLIGHT 7
Learning from social science perspectives

Social science methods and insights can enhance Federal global change research, assessments, and programs.

In March 2017, USGCRP's Social Science Coordinating Committee convened a three-day workshop, "**Social Science Perspectives on Climate Change**." The workshop brought together over 80 participants, including scientists and program managers from 13 Federal agencies, representatives from non-governmental organizations, and academic social scientists from four disciplines: anthropology, archaeology, geography, and sociology. Participants focused on identifying how social science perspectives, methods, and data can improve our understanding of global climate change as well as new opportunities and avenues for incorporating social science research into Federal climate research, assessments, and programs. To facilitate discussion, three white papers were developed by academic and Federal social scientists that focused on three themes: (1) characterizing differences between and within communities that affect *vulnerability* to climate change; (2) providing social science perspectives on on *drivers* of and *responses* to global climate change; and (3) identifying innovative *tools*, *methods*, and *analyses* to improve understanding of the interactions among human and natural systems under climate change. The workshop participants reviewed the white papers and provided input. The three white papers are now finalized and published and are available at https://www.globalchange.gov/content/social-science-perspectives-climate-change-workshop.

ADVANCING SCIENCE
INTEGRATIVE SCIENCE TOPICS

These selected topics illustrate how long-term, coordinated investments in scientific research into natural and human-caused processes of change can lead to tangible applications, including partnerships and science-based tools supporting rapid responses to and recovery from extreme events, forecasting of sea ice conditions for operational use, and building longer-term resilience to forces of global change.

Integrative Science Topics: Extreme Events

HIGHLIGHT 8
Supporting recovery from the 2017 hurricane season

Interagency collaboration supported recovery efforts after Hurricanes Irma and Maria.

During the 2017 hurricane season, hurricanes Irma and Maria, two of the most significant storms to affect Florida and the U.S. Caribbean in recent history, caused catastrophic damage that affected ecosystems, livelihoods, and economic stability throughout the region. USGCRP provided one venue for facilitating interagency efforts—involving USDA, DOE, NASA, NSF, DOI, and FEMA—that are tracking storm damage and recovery in forests and the agricultural sector and supporting recovery and resilience-building efforts in affected communities.

The USDA Forest Service (USDA-FS) and the USDA Caribbean Climate Hub, headquartered in San Juan, Puerto Rico, began post-hurricane work within days of the storms, initiating research activities to aid in recovery efforts and develop lessons learned from the storm impacts and recovery that can inform future responses. Damage assessments of rural and urban forests are being conducted to obtain information on management and reforestation needs, including salvage opportunities for downed trees. To better understand how and why some landscapes are more vulnerable to hurricane damage than others, scientists are assessing how land characteristics such as topography affected vegetation damage. USDA is also evaluating the vulnerability of agricultural operations in Puerto Rico to hurricanes, as well as the vulnerability of sectors such as communications, energy, and transportation that support agribusinesses; these assessments are being used to improve the delivery of information and programs to reduce risks from future extreme events. USDA, NSF, and university partners are also supporting hurricane recovery and resilience-building efforts in urban communities, including opportunities for governmental and community leaders, practitioners, and academics to reflect on lessons learned from these storms and to identify innovative solutions to promote resilience—such as community hubs that use data and visualization technologies to support and connect communities in addressing local issues.

In addition to direct effects on livelihoods, extreme events can degrade important ecosystem services. Mangrove forests in both Puerto Rico and Florida affected by Hurricanes Irma and Maria serve as protective barriers to storm surge. Tropical forests and mangrove forests damaged by the storms also have high rates of carbon exchange with the atmosphere and very high carbon sequestration potential that can be affected by ecosystem disruptions. The hurricanes affected areas that had recently been surveyed via NASA Goddard's Lidar, Hyperspectral, and Thermal Airborne Imager (**G-LiHT**), which creates 3-D high-resolution maps of forested areas—allowing for direct observation of the effects of storm damage on these ecosystems and their recovery. Pre-hurricane flights, conducted in spring 2017 by NASA Goddard through an award from DOE and NGEE-Tropics, collected data over about 12% of the is-land. After the storms, researchers conducted repeat flights between November 2017 and May 2018, with support from DOI and FEMA, based on interactions initiated through USGCRP's Carbon Cycle Interagency Working Group. USDA National Institute of Food and Agriculture, NASA, and DOE provided support for work on the ground, field validation of remote sensing observations, and analysis of results.

Preliminary evidence shows that five months after Hurricane Maria, more than half of the trees in Puerto Rican rainforests are damaged or were downed and 60% of protective coastal mangroves in Florida were destroyed[12]. Some areas and species are recovering faster than others; for instance, palm trees in Puerto Rico's El Yunque National Forest are taking advantage of sunlight provided by an open canopy[13]. When fully analyzed, observations from this multi-agency effort will provide an unprecedented picture of the damage and initial recovery from these two events and help improve understanding of how hurricanes change forest ecosystems. Such assessments can inform planning for recovery and rehabilitation of affected lands and preparation for future events.

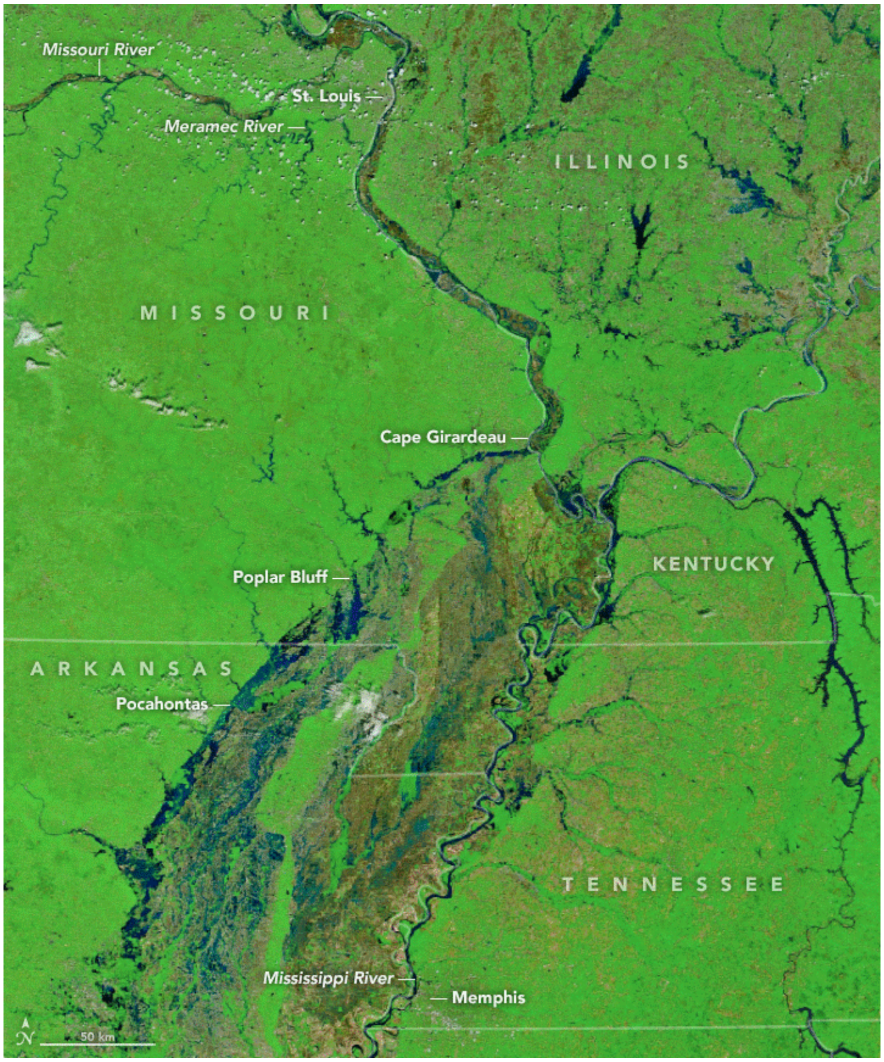
The Ten Thousand Islands mangrove ecosystem in the Florida Everglades pictured before (top, March 28, 2017) and after (bottom, December 1, 2017) Hurricane Irma, as captured by the NASA G-LiHT team. The greener vegetation in the top image is indicative of a healthier ecosystem; the bottom image shows significant damage to foliage and trees. Source: NASA.

HIGHLIGHT 9
Responding to the 2017 Midwestern floods

Interagency collaboration supported rapid response efforts.

Periods of heavy rainfall caused extensive flooding across much of the Midwestern United States and Mississippi River Basin in spring 2017, including widespread accumulation of 7–10 inches of rain, flash floods, and long-term river flooding. In response, NASA's Earth Science Disasters Program assembled a team of scientists at NASA's Marshall Space Flight Center in Huntsville, Alabama, other NASA centers, and NASA-affiliated partners to assist the U.S. Federal Emergency Management Agency (FEMA) and the U.S. National Guard in their emergency operations.

The Disasters Response Team created flood extent maps and assisted with the integration of remote sensing products for FEMA and the National Guard. The flood extent maps primarily relied on data from synthetic aperture radar, which has great value for flood monitoring because it can "see" through cloud cover that blocks other types of satellite imagery[14]. Maps were processed with help from collaborators at the University of Alaska Fairbanks. The team also used Landsat 8 visible/infrared sensors and data provided by the U.S. Geological Survey Hazards Data Distribution System to track flood waters and assist in overall emergency response.



Imagery captured by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard NASA's Terra satellite on May 2, 2017 showing flooding along several tributaries of the Mississippi River. The false-color image highlights vegetation (greens, browns), river, and flood waters (blues) from St. Louis to Memphis, along with several other affected towns and cities in Missouri, Kentucky, Arkansas, and Tennessee. Credit: NASA Earth Observatory.

HIGHLIGHT 10
Monitoring change in Alaska and the Arctic

By monitoring trends such as permafrost thaw, shifts in wildfire, and changing wildlife habitats, a multi-year field campaign seeks to provide the scientific basis for informed decision-making in response to change.

Climate change in the Arctic and Boreal Region is unfolding faster than anywhere else on Earth. Observations reveal reduced Arctic sea ice, widespread changes to coastlines and waterways, thawing of permafrost soils and decomposition of long-frozen organic matter, and shifts in ecosystem structure and function. These changes have far-reaching impacts in the region as well as implications for global climate[15]. As part of a broader effort to improve understanding of the vulnerability and resilience of ecosystems and society to a changing environment, NASA and its partners have begun a multi-year field campaign to investigate the ecological impacts of a rapidly changing climate in Alaska and northwestern Canada. The **Arctic-Boreal Vulnerability Experiment (ABoVE)** will build upon ongoing research sponsored by multiple Federal agencies, bringing together on-the-ground research with data collected by NASA airborne instruments, satellites, and other agency programs.

In the summer of 2017, an ABoVE airborne remote sensing campaign collected an extensive data set over study sites in Alaska and northwestern Canada. The campaign was coordinated with multiple U.S. agencies, including NASA, DOE, NSF, NOAA, USDA-Forest Service, U.S Geological Survey, U.S. Fish and Wildlife Service, Bureau of Land Management, National Park Service, and U.S. Army Corps of Engineers, as well as Canadian partners. Flights were coordinated across multiple field sites in Alaska and northwestern Canada during the growing season to link remote sensing data with key environmental and societal processes. ABoVE will continue the cooperative remote sensing campaign during the summers of 2018–2020 using the Airborne Visual Imaging Infrared Spectrometer, L-Band Radar, and possibly the Land, Vegetation, and Ice Sensor.

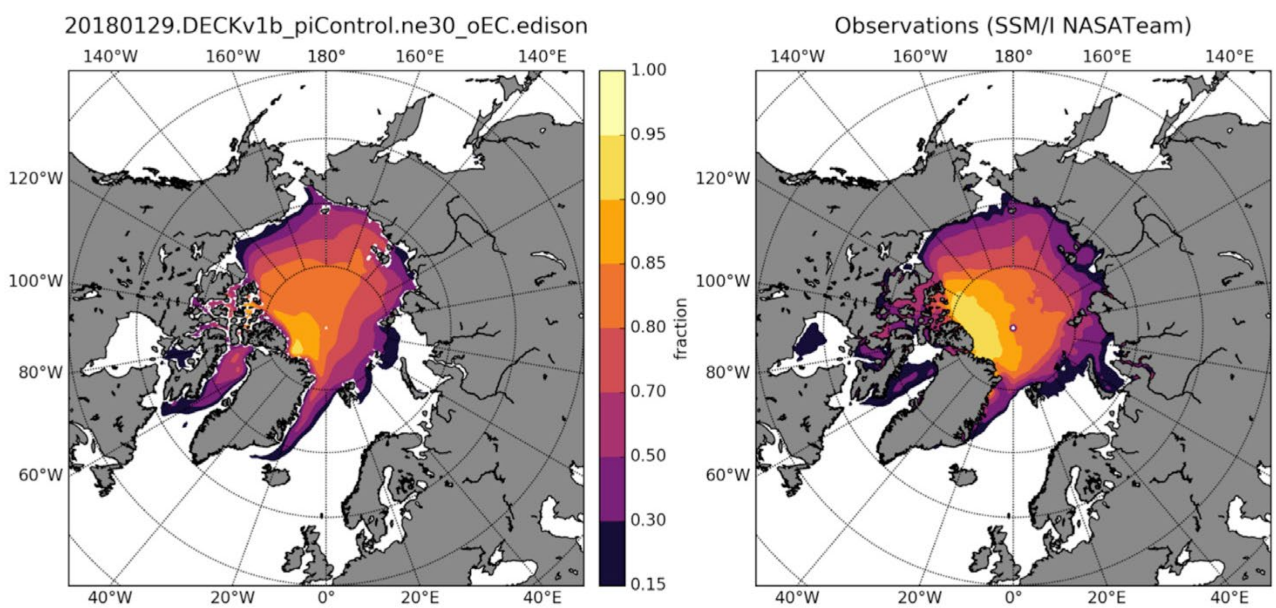
A lake near Fairbanks, Alaska shows signs of thawing permafrost below the surface—including "drunken trees" that tip over as soil shifts around their roots. Through the ABoVE campaign, scientists are investigating the impacts of warming temperatures on northern lakes like this one. Credit: Kate Ramsayer, NASA.

HIGHLIGHT 11
Predicting Arctic sea ice change

Interagency collaboration supports predictions of Arctic sea cover used by the U.S. Navy and other operational and research organizations.

Summer sea ice cover in the Arctic Ocean shrunk significantly since the early 1980s, with particularly rapid declines in recent years[16]. Arctic sea ice plays a key role in regulating weather and climate in and beyond the region[17], and projections of how sea ice cover will change in the coming years are critical for predicting climate change in the region and its influence on global climate. Several modeling centers that study such changes use the **CICE sea ice model**, first developed by scientists at DOE's Los Alamos National Laboratory, as a component of Earth system models that can predict future changes across weather and climate timescales. CICE simulates sea ice extent, thickness, and movement over seasonal to decadal timescales (see figure), offering a number of research and operational uses. One noteworthy application of CICE is in the U.S. Navy's sea ice prediction capability. The Navy disseminates daily sea ice forecast products to NOAA and to the multi-agency National Ice Center (NOAA, U.S. Navy, U.S. Coast Guard), while also using the model for special missions. CICE has also been adopted by research and operational organizations in more than twenty countries, including numerous climate modeling groups (including NOAA's Geophysical Fluid Dynamics Laboratory, NSF's Community Earth System Model, and DOE's Energy Exascale Earth System Model) as well as forecast centers operated by the National Weather Service, United Kingdom Meteorological Office, Environment Canada, and the Danish Meteorological Service.

In 2016, a group of CICE users and primary developers founded the international CICE Consortium as a vehicle for collaboration as the community continues to use and improve the model. The Consortium formalizes an existing collaborative alliance among a large group of participating universities, government agencies, and affiliated institutions. By coordinating innovations in both model code and analysis tools and allowing a greater number of modeling groups and agencies to use and contribute to this scientific resource, the Consortium serves to accelerate the transfer of innovations in sea ice modeling research and operational applications.

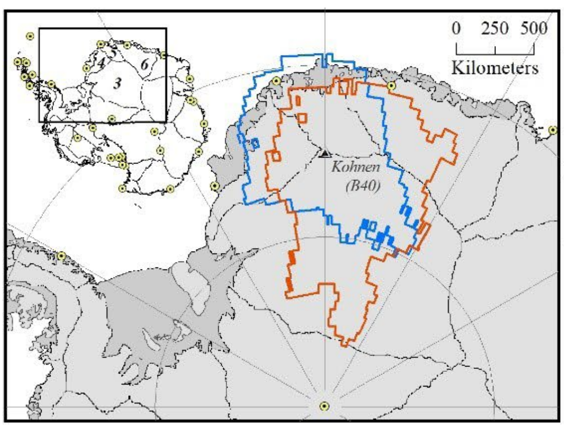


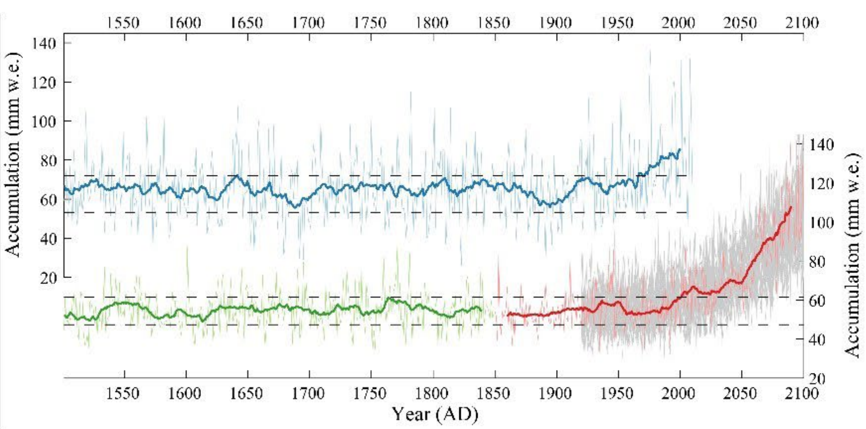
The figure shows long-term averages of Arctic summer sea ice concentration simulated by an adaptation of CICE/Icepack in the DOE's Energy Exascale Earth System Model (left panel) compared with observational estimates derived from measurements by the Special Sensor Microwave Imager satellite instrument (right panel). Source: DOE Los Alamos National Laboratory.

HIGHLIGHT 12
Modeling ice sheet change in Antarctica

Modeling efforts provide new data on the effects of climate change in Antarctica.

Between 1998 and 2016, warming in Antarctica has been rapid and significant. Recent observations also reveal increases in snowfall in western Queen Maud Land, East Antarctica that are unprecedented over the past two millennia. To investigate these changes, a team of NSF-sponsored researchers and NASA scientists merged observation-based NSF-funded research with global modeling efforts that benefited from NASA satellite and airborne-based data[18]. Researchers determined that models were underestimating snow accumulation and temperature increases in this region, with implications for sea level rise estimates based on contributions from the East Antarctic Ice Sheet. Updated climate model projections suggest that additional snowfall over Antarctica, largely due to atmospheric warming, is expected to partly offset dynamic ice losses by the end of the 21st century[19]. However, even small variations in the modeled snowfall accumulation rates created great uncertainty about the balance of ice loss and accumulation in Antarctica. The mitigating impact of higher snowfall rates is therefore not fully resolved, indicating a need for improved evaluation of global atmospheric model performance in Antarctica.





Left: *In the study area in Queen Maud Land, eastern Antarctica, the blue area experienced increased snowfall related to warming temperatures[20].* ***Right:*** *Until recently, annual snowfall, as recorded in the historical ice core record (blue), remained within preindustrial averages (dashed grey lines). Data modeled by the Community Earth System Model includes an artificially-controlled run (green) and an ensemble data run (red), showing the potential projected snowfall increases based on the NSF data recorded at Queen Maud Land. The grey area around the ensemble data is the margin for error. Source: NASA.*